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The Relation of the Density to The Permeability of Concrete

Civil Engineering

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THE RELATION OF THE DENSITY TO THE PERMEABILITY OF CONCRETE

BY

ALFRED HUGHLLYN HUNTER

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED, JUNE, 1909

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ALFRED HUGHLLYN HUNTER

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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The Relation of the Density to the Permeability of Concrete.

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INTRODUCTION.

Concrete is admirably adapted to a variety of the most important uses. For foundations in damp and yielding soils, subterranean masonry, retaining walls and reservoirs, under almost every combination of circumstances likely to be met with in practice, it is superior to brick masonry in strength, hardness and durability; is more economical; and in some cases is a safe substitute for the best natural stone.

In masonry constructed of stone or brick it is almost impossible to lay the stone or brick in such a manner as to give a monolithic structure. Where construction of such a nature is used for retaining walls, reservoirs, and in places where water tends to seep through, the walls must be thicker than the provision for equilibrium requires, in order that the amount of water passing through may be reduced. When concrete is used in such construction the thickness can be reduced considerably below that for brick or stone for an equivalent percolation, but the wall still will be heavier than necessary to maintain equilibrium. Attempts have been made to relieve this fault, but not all of them have been successful. Good results have been

obtained by care in putting a coat of neat cement on the inner surface of the structure or by a composition of asphalt or coal tar placed in the wall at a short distance from the inner surface. The degree of efficiency varies largely with the character of the labor employed so that no definite data can be obtained. The object of reducing the percolation is not merely to have an impervious material but to increase the life of the structure. Nearly every failure of masonry is due to the disintegration of the exposed surface, and the presence of water on the surface tends to make both the chemical and mechanical activities more marked.

Ordinary lime mortar absorbs between 50 and 60% of water by volume, while mortar made from the best Portland cement will absorb from 1/8 to 1/6 as much. Attempts have been made to reduce this absorbing power either by means of chemical compounds or by mechanical mixtures.

Theoretically any mixture which has no voids will have a maximum density. At the same time a dense concrete has a high tensile strength and a low permeability. If there is not enough mortar to fill the voids the concrete will be weak and porous. On the other hand an excess of mortar increases the cost, decreases the strength and changes the permeability but in what manner and to what extent has not yet been fully determined. With these considerations in mind it seems feasiable to obtain a concrete of maximum density; with such a concrete to determine the porosity; and by a process of comparison to note the relation of

porosity to density.

To secure a mixture of maximum density the percentage of voids must be reduced to a minimum. The proportion of voids is independent of the size of particles, but depends upon the gradation of the sizes, and varies with both the form and surface of the stone. An aggregate of perpectly smooth spheres of equal size has approximately 26% voids if closely packed. In the case of crushed stone the voids are very much greater due to the rough faces and projecting corners.

In order to determine the quantities of different sizes of stone necessary to produce a maximum density, the curve given by Fuller and Thompson in their experiment with Jerome Park material was used. This curve has been determined by actual experiment and in order to facilitate matters mathematical curves were fitted to them for convenience in plotting. The curve consists of an ellipse and a tangent straight line. The point of tangency of the ellipse and straight line is found to be on a vertical ordinate whose abscissa is about one tenth of the abscissa for the maximum particles of stone.

The general equation of the ellipse about the vertical axis is $y = \frac{b^2}{a^2}\sqrt{a^2 - x^2}$. This is simple for plotting and the value of y is determined by the relation of a and b, the major and minor axes. The values of a and b are found to vary for different maximum sizes of stone, and for stone having a maximum size of 0.45" , a = 0.098 inches and

b = 28.39 percent.

For the data contained in this article the three curves shown in Plate I were used. The equation of the *first* curve was as given above, consisting of an ellipse and a tangent line; the second was the same as the first one except that values of a and b were each increased 50 percent. The third was simply a straight line connecting the origin of coordinates to point whose abscissa is 0.45 inches, and ordinate 100 percent.

DESCRIPTION.

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Cement.

Chicago A-A, Portland cement from the regular shipments to the University was used in all tests. The cement was tested according to Specifications of American Society of Civil Engineers for all tests. The results of the above mentioned tests are given in Table 6.

Stone.

The stone used was Joliet Limestone ranging in size from 0.45 inches as a maximum down to dust. The specific gravity and weight per cubic foot was determined from 10 - 12 gram samples on an analytical balance.

The sieves used in sifting the stone were circular, 6 inches in diameter and 2 1/2 inches deep, and were identical in form to those used in determining the fineness of cement. All data pertaining to the commercial number and size of these seives are given in Table 7. The values for the diameter of the largest size of stones passing each sieve were obtained from tables shown by Taylor and Thompson and these checked very closely with the ones shown in the Transactions of the American Society of Civil Engineers for 1906.

The samples tested were molded in steel rings 6 inches in diameter 2 inches high. The rings were measured carefully so that their volumes could be accurately determined.

Apparatus.

The permeability apparatus used was practically the same as that used by the Structural-Materials Testing Laboratories of the United States Geological Survey at St. Louis. The apparatus is shown in Plate 2. It consisted of two castings 3/4 inch thick between which the disks were clamped. The disk is fitted at either end with a rubber gasket and in the later disks a thin coating of asphalt was added so as to insure water tight connections without excessive tension in the bolts connecting the castings. The water enters through a 1/2 inch nipple screwed into the upper casting. A funnel was riveted to the lower plate in order that the water passing through could be collected in a vessel. In the experiments conducted in the laboratory, the water was collected in a graduate or a flask fitted with a stopper through which the end of the funnel protruded. In the case of the graduate some slight error resulted from evaporation but in the closed flask no evaporation was possible.

The materials used in the disks was proportioned according to the maximum density curves. The cement used was weighed out and then the given quantities of the various sizes of crushed stone were added. A uniform mixture was obtained by mixing thogoughly with a trowel while dry. Then the water was added and the material mixed for 5 minutes.

The mixing being completed the concrete was placed in the iron rings in thin layers and tamped with the 2 inch round tamper shown on Plate 3

The disks were filled flush to the top and the surface left as nearly level as could be done with the tamper. The specimens were then covered with a moist cloth for 24 hours, after which they were placed in a moist chamber and left for 6 days before being tested.

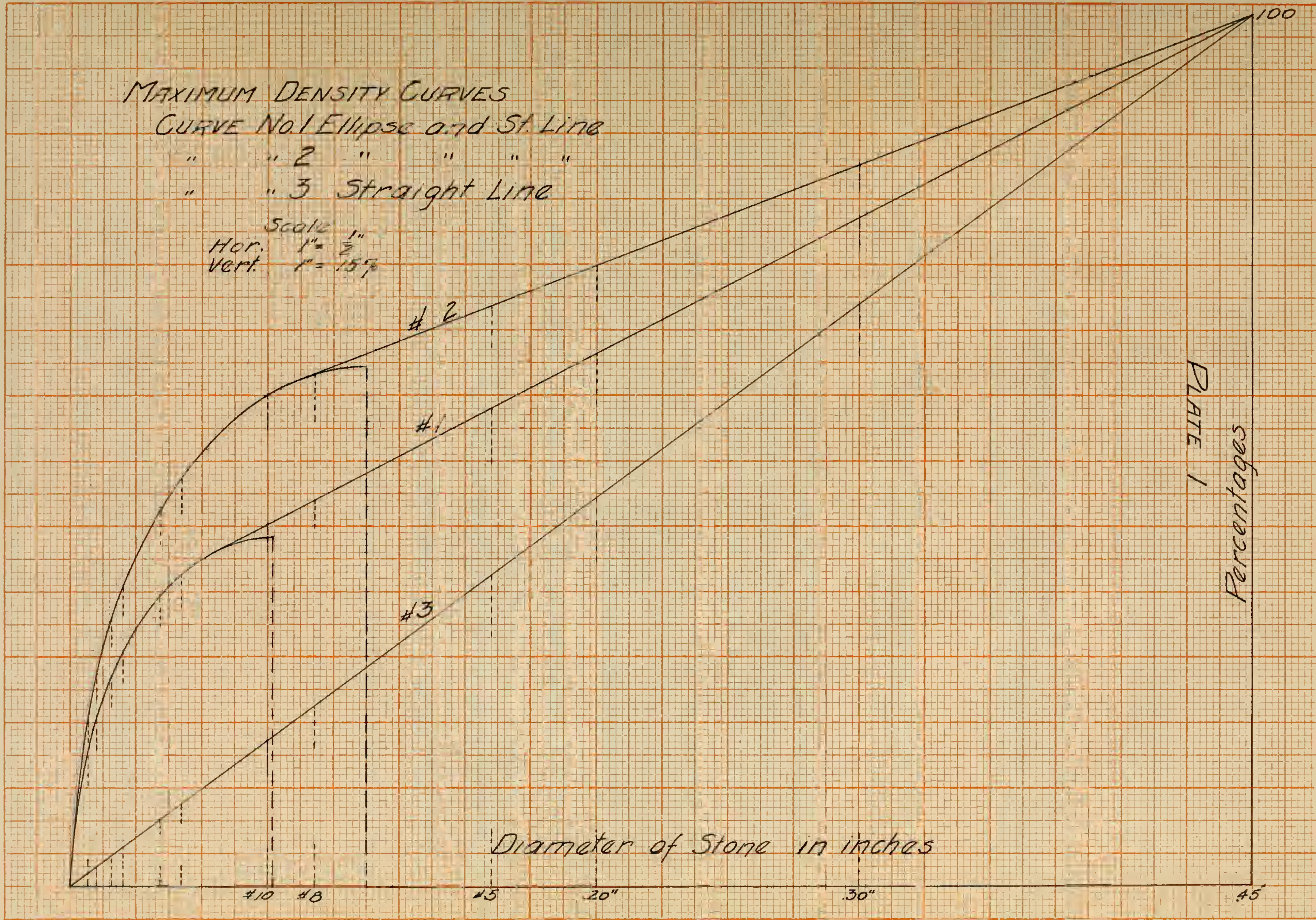
Disks numbered 1 - 11 inclusive were made according to curve # 1 and all of them contained 11 percent of water except disk number 2, which had 10 percent, Disks 12 and 13 were the same as the preceding ones but contained an excess of fine material. This fine material which was added consisted of stone dust passing sieve #74 and was equal in amount to that passing sieve #40 and below. Disks No. 14 - 16 inclusive were made according to curve #3, while disks #17 - 19 inclusive were made in accordance with curve No. 2.

Volumetric Tests.

The density of the mixture was determined by means of volumetric tests made upon every disk tested.

The material for the disk was mixed in a galvanized iron pan with an ordinary five inch trowel. The mortar was placed in the ring and thoroughly tamped. The exact amount of the material contained in the ring was determined by weighing the ring and contents. From the exact measurements of the ring and the specific gravity of the concrete, the weight of the ring when full was calculated. In this calculation the ring is assumed

to be entirely free from voids. The difference between the actual and calculated weights of the contents of the ring is the amount of voids. This number divided by the actual volume of the disk and multiplied by 100 gives the percentage of voids. The results of the volumetric tests are given, for each disk in Table No. 4.



U. OF I. S. S. FORM 3

TABLE I

WEIGHTS IN MIXTURE FROM CURVE Nº I

Sieve	Percentage			Weight	
No.	%	Cement	Stone	Cement	Stone
Pan	7.00	7.00		175.00	
200	7.10	7.10		177.50	
100	2.00	2.00		50.00	
74	3.60	2.70	0.90	67.50	22.50
60	4.80		4.80		120.00
40	2.50		2.50		62.50
30	6.00		6.00		150.00
20	2.50		2.50		62.50
16	5.62		5.62		140.50
10	3.18		3.18		79.50
8	10.30		10.30		257.50
5	6.25		6.25		156.25
0.20"	15.65		15.65		391.25
0.30"	23.50		23.50		587.50
0.45"					
	100.00	Total	Am't.	470.00	2030.00

TABLE 2

WEIGHTS IN MIXTURE FROM CURVE N° 3

Sieve No	Percentages %	Cement	Stone	Weights Cement	Stone	Stone
Pan	0.90	0.90				
200	0.42	0.42				
100	0.23	0.23		38.75		
74	0.78		0.78		19.50	15.10
60	1.35		1.35		33.75	26.10
40	0.77		0.77		19.25	14.95
30	3.22		3.22		80.50	62.20
20	1.71		1.71		42.75	33.10
16	7.00		7.00		175.00	135.90
10	4.37		4.37		109.25	84.45
8	14.85		14.85		371.25	286.85
5	9.04		9.04		226.00	174.60
0.20"	22.17		22.17		554.25	427.25
0.30"	33.19		33.19		829.75	640.75
0.45"						
	100.00	Add	Cement	560.00		
		Total	Amt.	598.75		1901.25

TABLE 3

WEIGHTS IN MIXTURE
FROM
CURVE N°2

Sieve	Percentage			Weights		
No	%	Cement	Stone	Cement	Stone	
Pan	15.00	15.00		375.00		
200	2.50	2.50		62.50		
100	3.28	2.70	0.58	67.50	14.50	
74	2.75		3.75		93.75	
60	5.82		5.82		145.50	
40	3.10		3.10		77.50	
30	7.75		7.75		193.75	
20	4.85		4.85		120.50	
16	9.38		9.38		234.50	
10	3.60		3.60		90.00	
8	7.60		7.60		190.00	
5	4.65		4.65		116.25	
0.20"	11.40		11.40		285.00	
0.30"	17.35		17.35		433.75	
0.45"						
	100.00	Total	Amt.	505.00	1995.00	

Table 4

Percolation in Grams

Disk No.	Composition: Curve	Composition: M.S. Stone	Composition: Percent Water	Composition: Percent Voids	Wt. grams	Age Days	Grams Water Passing per Day: 1	2	3	4	5	6	7
1	No. 1	0.45"	11	10.4	2400	7	1700	133	61	38	22	19	16
2	"	"	10	13.2	2300	7	4200	100	780	218	128	104	95
3	"	"	11	11.0	2340	7	260	93	62	25	19	10	4
4	"	"	11	9.2	2340	7	—	198	77	28	24	14	10
5	"	"	11	12.1	2350	7	210	83	46	25	14	10	8
6	"	"	11	13.4	2340	7	258	96	51	27	18	12	10
7	"	"	11	11.6	2310	7	263	92	37	22	12	8	5
8	"	"	11	10.2	2310	7	296	65	28	15	11	8	4
9	"	"	11	11.1	2320	7	600	145	110	63	46	23	17
10	"	"	11	11.1	2320	7	415	105	38	18	10	6	2
11	No. 1a	"	11	9.2	2380	7	105	50	23	12	12	8	5
12	No. 1a	"	11	13.4	2290	7	30	95	0	0	0	0	0
13	"	"	11	10.4	2400	7	70	0	0	0	0	0	0
14	No. 3	"	11	17.0	2247	7	238	169	56	49	38	40	19
15	"	"	11	13.0	2312	7	70	171	73	64	43	43	23
16	"	"	11	15.2	2253	7	441	160	54	46	33	32	18
17	No. 2	"	11	11.0	23.65	7	126	60	19	13	9	7	4
18	"	"	11	12.0	23.17	7	96	60	9	4	1	0	0
19	"	"	11	13.5	23.43	7	42	32	7	4	2	0	0

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Table 5

Percolation
in Ounces
per Square Inch per Day

Disk No.	Day 1	2	3	4	5	6	7	Total
1	6.731	0.381	0.195	0.099	0.064	0.056	0.049	7.575
2	16.860	5.250	2.508	0.565	0.375	0.305	0.291	25.974
3	1.031	0.232	0.167	0.077	0.049	0.028	0.013	1.597
4	——	0.477	0.208	0.086	0.062	0.039	0.032	0.904
5	0.708	0.206	0.119	0.070	0.039	0.028	0.028	1.198
6	0.869	0.239	0.132	0.076	0.051	0.034	0.035	1.436
7	0.788	0.236	0.096	0.067	0.031	0.023	0.023	1.264
8	0.877	0.151	0.076	0.046	0.029	0.023	0.018	1.230
9	1.928	0.337	0.284	0.163	0.135	0.062	0.048	2.957
10	1.334	0.272	0.103	0.053	0.029	0.017	0.006	1.814
11	0.337	0.129	0.062	0.031	0.035	0.022	0.014	0.630
12	0.084	0.291	0	0	0	0	0	0.375
13	0.197	0	0	0	0	0	0	0.197
14	0.975	0.368	0.164	0.132	0.117	0.003	0.058	1.887
15	0.277	0.348	0.214	0.172	0.132	0.103	0.077	1.323
16	1.750	0.372	0.158	0.124	0.101	0.083	0.055	2.643
17	0.502	0.131	0.056	0.035	0.028	0.018	0.012	0.782
18	0.381	0,130	0.026	0.011	0.003	0	0	0.551
19	0.167	0.069	0.021	0.011	0.006	0	0	0.274

TABLE 6
TESTS OF CHICAGO A-A PORTLAND CEMENT

FINENESS

Sieve	Retained	Passing	% Retained	% Passing
50				
74	27	973	2.7	97.3
100	42	931	4.2	93.1
200	202	729	20.2	72.9
Pan	729		72.9	

TENSILE STRENGTH

7 Days		28 Days	
Neat	1-3	Neat	1-3
610	91	815	168
662	119	775	210
750	84	815	172
690	50	815	156
714	89	785	172
740	—	865	166
Av 694	87	812	174

SPECIFIC GRAVITY

No.	Wt.	Vol.	Sp. Gr.
1	64	20.41	3.13
2	64	20.14	3.17
	Average		3.15

CONCLUSION.

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As has been stated, previous tests indicate that the greatest strength from any given percentage of cement was obtained when the concrete was of the greatest possible density, that is having the least percentage of voids, and further that the greatest density was obtained when all the materials were proportioned so as to give a regular mechanical analysis curve approaching a parabola. It also appeared probable that concrete of the greatest density would be the the least permeable by water.

With the foregoing conclusions in mind it was thought profitable to test specimens made by a maximum density curve and compare the results so obtained to the samples made from mixture having a known variation from that of maximum density.

Test specimens from 1 - 10 inclusive were made from mixtures obtained from curve No. 1 and were found to have an average of 11.1 per cent of voids and 1.259 ounces per square inch per week of percolation. Disk No. 2 was not included in this average as 10 instead of 11 per cent of water had been used and the percolation which resulted was very high. This lower percentage of water in disk No. 2 seemed to cause the cement to adhere to the stone particles in a manner similar to that shown in ordinary dough and no amount of tamping caused the water to flush to the surface. The other examples have considerable

variation in the amount of water passing but no so much but that any one could be classified as fairly representative of the mixture. Disk No's 11 - 13 inclusive were the same as the ones just mentioned but containing an excess of fine material, the amount of which is given in a previous paragraph. The average per cent of voids and percolation in ounces per square inch per week was found to be 11.0 and 0.286 respectively. The percentage of voids remained very nearly the same but the amount of percolation was reduced to a great extent, so much so that in two of the samples Nos. 12 and 13 the evaporation equalled the percolation for the last 5 days. This result although not conclusive seems to bear out the statement of other experimentors , that an excess of fine material reduces the amount of water passing to a lower value than that obtained from the maximum density curve samples.

Disk Nos. 17 - 19 inclusive are made from curve No.2 and gives results as follows; voids 12.26 per cent ; percolation 0.536 ounces per square inch per week. This small amount of percolation can be explained by the fact that there was considerable more fine material in the mixture than that obtained from the maximum density curve, and at the same time the decrease in the amount of the larger size of stone caused a decrease in the density.

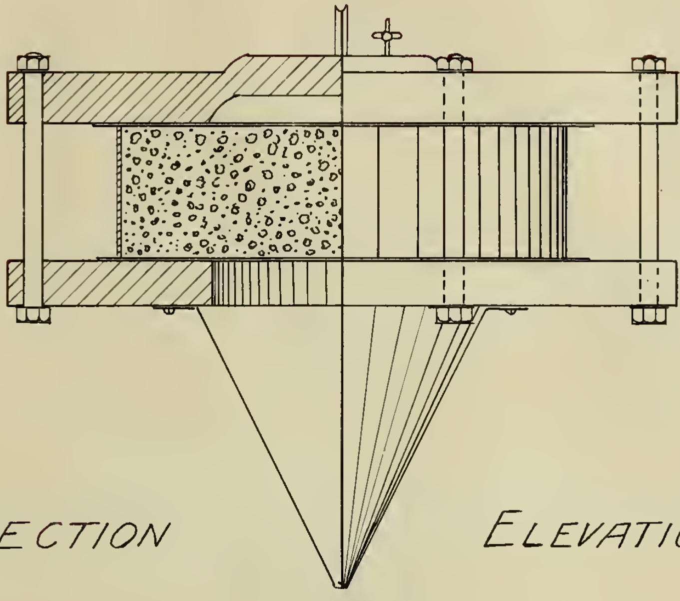
Disk Nos 14 to 16 inclusive were made according to data obtained from the straigh line curve shown at 3 Plate 1,

and had 15.7 per cent voids and a percolation of 1.952 ounces per square inch per week. These values when compared to those of curves No's. 1 and 2 are found to be much in excess both with regard to percolation and to the percentages of voids.

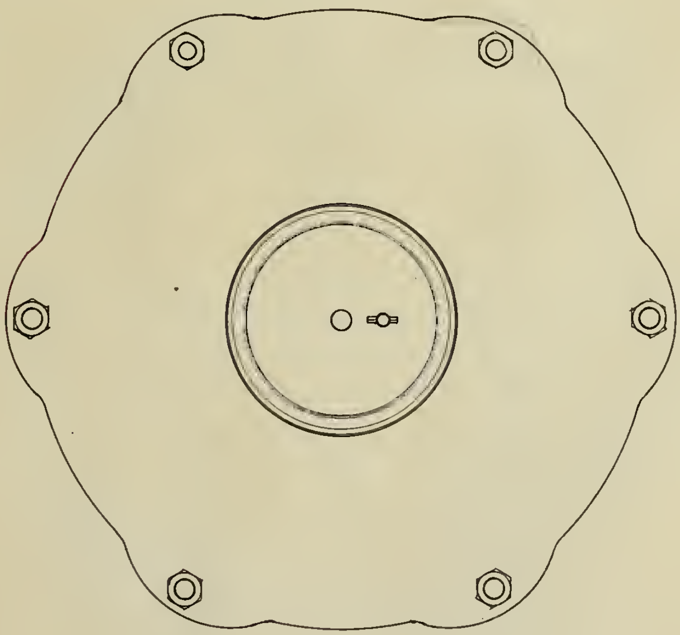
From the results obtained above the permeability is found to vary inversely as the density of the mixture and that an excess of fine material changes the density but slightly and reduces the permeability. Also that in tests of this character better results may be obtained by an excess of water in making the disk. The results while not conclusive, on account of the small number of tests, give data of such a character that would indicate that mixtures which approach the maximum density curve are those which contain an excess of fine material will be the most satisfactory where a low permeability is required.

In further experiments of a similar nature effort should be made to secure uniform water pressure, for in the experiment described above the pressure was found to range from 45 lb. per square inch as normal to occassional pressures which would blow out the asphalt between the gasket and the disk. The effect of this variation was noticeable in the daily readings of some of the specimens.

PLATE 2



SECTION ELEVATION



TOP VIEW

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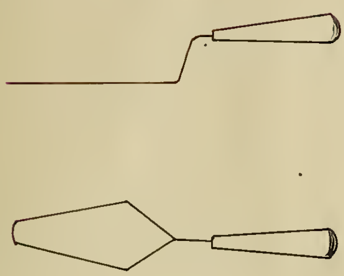
PLATE 3



TROWEL

TAMPER

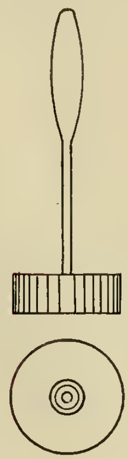


TABLE 7

SIEVES

Number	Diam in inches
	0.45"
	0.30"
	0.20
5	0.16
8	0.093
10	0.075
16	0.045
20	0.034
30	0.020
40	0.016
60	0.0115
74	0.0071
100	0.0058
150	0.0036
200	0.0027
Pan	—